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TECHNICAL REPORT

WAL TR 768.1/1(c)
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WATERTOWN ARSENAL

LABORATORIES

TERMINAL BALLISTIC STUDY OF FLECHETTES (U)

BY
C. A. RIDDLE

FC

O.O. PROJECT: TW-121, LONG RANGE DEVELOPMENT OF MASS COUNTER-ASSAULT AMMUNITION
D/A PROJECT: 5A04-01-002
REPORT NO.: WAL TR 768.1/1(c)
FILING SUBJECT: CANISTER AMMUNITION, FLECHETTE

DECEMBER 1958

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CANISTER AMMUNITION, FLECHETTE

TERMINAL BALLISTIC STUDY OF FLECHETTES (U)

TECHNICAL REPORT

By

C. A. Riddle

O.O. Project: TW-121, Long Range Development of Mass Counter-Assault Ammunition
D/A Project: 5A04-01-002
Report No.: WAL TR 768.1/1(c)
Filing Subject: Canister Ammunition, Flechette

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TITLE

TERMINAL BALLISTIC STUDY OF FLECHETTES (U)

ABSTRACT

Army V_{50} ballistic limits were determined with the FL-17, FL-17C-4, 10, 12, 14, and 16 flechettes against aluminum targets at 0° obliquity; and with the FL-17, FL-17D-6, and FL-17C-12 and 16 flechettes against aluminum targets at 45° obliquity.

Employing the ballistic limit data, deMarre-type equations were derived for the flechette designs and obliquities studied. A satisfactory reproduction of the ballistic data within a maximum error of 6% was obtained with the equations derived. The order of superiority of flechettes against the aluminum targets evaluated was: tabulated

0° Obliquity

1. FL-17
2. FL-17C-10, 12, 14, and 16 (all equal)
3. FL-17C-4

45° Obliquity

1. FL-17
2. FL-17D-6, FL-17C-12 and 16 (all equal)

C. A. Riddle
C. A. RIDDLE
Engineering Technician

APPROVED:

J. F. Sullivan
J. F. SULLIVAN
Director
Watertown Arsenal Laboratories

INTRODUCTION

As part of a continuing effort to develop improved canister ammunition for employment against massed infantry assaults, such as encountered in Korea, the Ordnance Corps has been investigating flechette-type missiles of various designs. Numerous designs have been evaluated for flight stability, range-velocity characteristics, quantity and size of loading, economy of fabrication, effect of manufacturing deviations on flight performance, etc., by Ordnance Corps contractors under Contracts DA-33-008-ORD-160, DA-33-008-ORD-1257, and DA-33-008-ORD-1562. As part of this program, Watertown Arsenal had been requested to conduct terminal ballistic studies with various flechette designs against lightweight armor materials, such as employed in armored vests, helmets, and personnel carriers. Materials chosen for this study were unbonded nylon, aluminum, and Hadfield-manganese steel. These materials were evaluated with the FL-17 (8-grain) flechette at 0° and 45° obliquity and the resulting data published.[1] It was concluded that unbonded nylon, and probably all fabric materials that fail to deform the missile, offers very little ballistic resistance to flechette attack, and that Hadfield-manganese steel, because of a regrettable variation in ballistic performance of similar plate, is not suitable for distinguishing variations in ballistic performance of individual flechette designs. Accordingly, it was recommended that future terminal ballistic flechette studies be conducted with aluminum as the target material. This report covers these tests and also incorporates the data previously gathered with flechettes against aluminum armor. Of the seven flechette designs studied it is possible to differentiate between penetration performance against the aluminum armor material and to select the missile that exhibits optimum performance.

It was deemed desirous to extend the ballistic limit data to higher velocity levels, however, limitations imposed by structural failures of the various flechette designs during set-back in launching from the gun, restricted the upper velocity limits that could satisfactorily be employed with each design.

MATERIALS

Flechettes

The following seven flechette designs were employed to determine ballistic limit data for comparisons of penetration performance:

	Type	Weight
1.	FL-17C-4	4 Grains
2.	FL-17D-6	6 Grains
3.	FL-17	8 Grains
4.	FL-17C-10	10 Grains
5.	FL-17C-12	12 Grains
6.	FL-17C-14	14 Grains
7.	FL-17C-16	16 Grains

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These flechettes are illustrated in Figure 1 together with a tabulation of mean dimensions. In order to utilize the previous data, accumulated with the FL-17 flechette, firing was continued with this design in preference to the later FL-17D-8. It has since been determined that the newer FL-17D-8 design, which differs from the FL-17 in nose contour and a .005" larger diameter across the fins, exhibits superior velocity-decay performance and greater depth of penetration into celotex targets, particularly in the supersonic velocity regions.[2]

Targets

Because of the previously noted limitations imposed by unbonded nylon and Hadfield-manganese steel as a means of differentiating between ballistic performance of the various flechettes, 2024-T4 aluminum alloy was employed as the target material. Army V_{50} ballistic limits were determined at 0° and 45° obliquity against the target thicknesses tabulated in Table I.

PROCEDURE

Method of Measurement

In order to evaluate the armor penetration capabilities of the various flechette designs a number of rounds of each were fired at the aluminum targets and Army V_{50} ballistic limits determined. A sufficient number of rounds were fired so that projectile defeat and penetration of the target were achieved over the velocity range traversed. According to the Army criteria, a complete penetration of the armor occurs when a hole or crack on the reverse side of the plate, caused by the missile impacting the target, is sufficient to permit the passage of light. The V_{50} Army limit is that velocity at which a 50% probability exists that the missile will achieve a complete penetration of the armor. The results from the ballistic test plate firings are incorporated in the following formula for the calculation of the V_{50} ballistic limit:

$$V_{50} = \frac{\Sigma V + K(NP - NC)}{NP + NC}$$

and

$$K = \frac{V_{HP} - V_{LC}}{2}$$

and if

$$V_{LC} > V_{HP},$$

then

$$K = 0$$

where

V_{HP} = Highest velocity resulting in a partial penetration

V_{LC} = Lowest velocity resulting in a complete penetration

$V_{HP} - V_{LC}$ = Zone of mixed results

ΣV = Sum of velocities within the zone of mixed results including V_{HP} and V_{LC}

NP = Number of partial penetrations within the zone of mixed results including V_{HP}

NC = Number of complete penetrations within the zone of mixed results including V_{LC}.

Flechette velocities were determined by their passage through a pair of lumline screens spaced 10 feet apart and connected to a 400 Kc counter-chronograph. The first screen activated and the second screen stopped the chronograph, thus permitting the determination of the missile velocity at a point midway between the screens located at a distance of 7.5 feet from the target. Since comparisons of individual flechette ballistic limits are made relative to this velocity, corrections were not applied for velocity loss from the midpoint of the lumline screens to the target.

Penetration Equations

A plot on log-log paper of Army V_{50} ballistic limit versus the caliber thickness ratio yields the curves shown in Figures 2 and 3. The slope of the straight line that most closely fits the data then corresponds to the exponential function $n/2$, and the intercept at $e/d = 1$ yields the constant term K in the following equation:

$$V_L = K\left(\frac{e}{d}\right)^{\frac{n}{2}},$$

which is derived from a deMarre penetration equation that has previously been described in detail.[1,3,4,5]

The exponent $n/2$ in the foregoing equation very often permits an interpretation of the mechanism of armor penetration dependent upon projectile nose shape and armor hardness. In the case of flechette penetration, however, the exponents are quite different from those normally encountered in deMarre equations and indicate mechanisms of penetration of a different type than normally observed for kinetic energy armor piercing projectiles. Thus, the equations developed for the different flechettes are presented only as a convenient method of representing the ballistic test results and apply only to aluminum armor material with the flechettes studied.

RESULTS AND DISCUSSION

A summary of the ballistic test data is presented in Table I, and the penetration equations derived from these data are contained in Table II. Presented in Table III are the actual ballistic limits obtained (V_{50}) and a comparison with those computed from the penetration equations (V_L). Close agreement is demonstrated, the average deviation for 50 ballistic limits being 2.5% between the actual and derived limits. Examination of Figures 2 and 3 demonstrates that the FL-17 flechette defeats the aluminum targets at lower velocities than the remaining flechettes. The light, FL-17C-4 flechette is inferior to the FL-17 at 0° obliquity by approximately 500 ft/sec over the entire range of target thicknesses tested. The heavier missiles, FL-17C-10, 12, 14, and 16 all demonstrate similar performance and are considerably inferior to the FL-17 against the thinner targets, while approaching the FL-17 in performance against the heavier targets at an e/d ratio of 3.5. Above this point inferior performance is again manifested for the FL-17C-12 missile in the only two cases tested with heavier flechettes. At 45° obliquity superior performance over the entire range of targets evaluated is demonstrated for the FL-17 design over the FL-17D-6, FL-17C-12, and 16, the superiority increasing slightly as the armor thickness increases.

RECOMMENDATIONS

Because of the superior performance of the FL-17 flechette it should be selected in preference to the other designs tested for canister filler. However, before establishing the FL-17 as standard filler, similar terminal ballistic studies should be conducted with the FL-17D-8 flechette to determine which of these two designs exhibit optimum penetration performance against aluminum targets.

Use of these flechette designs either lighter or heavier in weight than the FL-17 series is not recommended since no advantage of terminal performance is gained with these missiles, and only in the lighter designs is there any advantage gained in density of loading.

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1. MULDOON, R. A., "Terminal Ballistic Study of FL-17 Flechette" (U), WAL Report No. WAL TR-763/899(c), January 1958.

2. WOLF, M. J., Final Progress Report No. 6 under Contract No. DA-33-008-ORD-1562, "Design of Canister Fillers," 1 April 1957 to 31 December 1957.

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4. MULDOON, R. A., "Ballistic Evaluation of Various Personnel Armor Materials," WAL Report No. 710/1044, March 1954.

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TABLE I

SUMMARY OF PENETRATION DATA

Flechette vs 2024-T4 Aluminum

0° Obliquity								
Flechette	[illegible]	BL	HP	IC	ZMR	NP	NC	Rounds Fired
FL-17C-8	.087	1420	1555	1310	245	8	7	31
	.156	2040	2300	1690	410	8	8	30
	.193	2425	2540	2220	320	18	10	34
	.250	2771	2900	2570	290	7	16	34
FL-17	.100	973	1850	905	795	7	16	44
	.130	1054	1875	1605	75	4	3	59
	.156	1412	1470	1355	65	7	1	63
	.192	1517	1565	1450	75	5	8	45
	.250	1884	2030	1440	600	21	13	60
	.312	2408	2490	2140	320	21	21	58
	.350	2517	2540	2430	120	4	5	15
	.400	2982	3030	2960	70	6	3	19
	.450	3268	3318	3220	90	6	5	20
FL-17C-10	.081	1502	1815	1500	300	12	10	35
	.158	1753	1775	1620	115	12	5	31
	.185	2032	2260	1900	360	12	20	36
	.252	2141	2300	2030	278	11	14	33
FL-17C-12	.081	1463	1600	1430	70	2	7	29
	.163	1821	2080	1530	560	19	11	31
	.188	1830	1940	1740	200	21	9	26
	.252	2146	2180	2010	170	11	8	32
	.312	2183	2250	2040	210	18	6	38
	.350	2367	2400	2250	25	3	4	13
	.400	3000	2725	2860	[illegible]	8	2	33
	.450		3445					
FL-17C-14	.081	1290	1305	1265	50	8	4	37
	.160	1830	1660	1565	98	14	4	39
	.191	1700	1830	1640	150	14	14	35
	.249	1948	2050	1830	220	18	13	35
FL-17C-18	.080	1375	1415	1270	145	14	7	38
	.161	1655	1745	1610	135	10	16	38
	.189	1600	1730	1650	80	10	11	38
	.248	1900	2010	1720	290	17	14	40
	.313	2162	2300	2135	65	3	4	16
	.35	2330	2330	2330	6	1	1	16

(Continued)

TABLE I (Continued)

45° Obliquity								
Flechette	e	BL	[illegible]	LC	[illegible]	[illegible]	[illegible]	Rounds Fired
FL-17D-8	.180 .190 .250 .312	[illegible] [illegible] 2675 3865	[illegible] 3230 [illegible] 4085	[illegible] [illegible] 3400 [illegible]	186 [illegible] [illegible] [illegible]	7 13 11 10	[illegible] [illegible] 11 4	[illegible] 21 [illegible] 13
FL-17	.100 .130 .150 .160 .252 .310	[illegible] 1813 [illegible] [illegible] 2634 3643	2010 [illegible] 2346 2670 [illegible] 3750	[illegible] [illegible] [illegible] [illegible] 2570 [illegible]	245 [illegible] [illegible] [illegible] [illegible] 750	7 16 [illegible] [illegible] 17 [illegible]	7 [illegible] [illegible] [illegible] 7 [illegible]	[illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
FL-17C-18	.150 .185 .256 .314	2340 2780 [illegible]	[illegible] [illegible] [illegible] [illegible]	[illegible] [illegible] [illegible]	179 [illegible] [illegible]	[illegible] 16 [illegible]	[illegible] 13 7	24 21 [illegible]
FL-17C-18	.150 [illegible] [illegible] .312	2160 [illegible] [illegible] [illegible]	[illegible] [illegible] [illegible] [illegible]	[illegible] [illegible] [illegible] [illegible]	186 [illegible] [illegible] [illegible]	[illegible] 17 16 4	13 11 [illegible] [illegible]	[illegible] [illegible] [illegible] 13

[illegible]

[illegible]

TABLE II

DERIVED PENETRATION FORMULAS

Flechettes vs Aluminum

Flechette Design	Obliquity (Degrees)	Range of Target Thickness (Inches)	No. of Targets Tested	Equation	Maximum Deviation (%)
FL-17C-4	0	.067-.250	4	$V_L = 1100(\frac{e}{d})^{.731}$	6.6
FL-17	0	.100-.400	6	$V_L = 720(\frac{e}{d})^{.800}$	8.1
FL-17C-10	0	.091-.252	4		
FL-17C-12	0	.091-.456	6	$V_L = 1340(\frac{e}{d})^{.387}$	6.1
FL-17C-14	0	.091-.240	4		
FL-17C-16	0	.099-.250	6		
FL-17D-8	45	.150-.312	4		
FL-17C-12	45	.150-.316	4	$V_L = 1370(\frac{e}{d})^{.644}$	5.3
FL-17C-16	45	.150-.3125	4		
FL-17	45	.100-.310	6	$V_L = 1470(\frac{e}{d})^{.572}$	3.9

TABLE III

COMPARISON OF MEASURED AND CALCULATED BALLISTIC LIMITS

0° Obliquity						
Flechette	w	e/d	V_{50}	V_L	ΔV	% Deviation $\left(\frac{\Delta V}{V_{50}}\right) \times 100$
FL-17C-4	.097	1.46	1436	1432	- 4	-0.4
	.150	2.35	2048	[illegible]	- 17	-0.8
	.196	3.18	2423	2428	- 3	-0.1
	.250	4.03	2771	2755	+ 16	+0.6
FL-17	.100	1.300	973	950	+ 23	+2.4
	.120	1.47	1054	1088	- 34	-3.2
	.150	2.17	1412	1340	+ 72	+5.1
	.192	2.67	1517	1525	- 8	-0.5
	.250	3.47	1584	[illegible]	- 21	-1.3
	.312	4.33	2400	2350	+ 50	+2.1
	.350	4.86	2517	2571	- 50	-2.9
	.400	5.56	2792	2680	+112	+3.7
	.450	6.25	3262	3160	+102	+3.1
FL-17C-10	.091	1.14	1502	1410	+ 92	+6.1
	.150	1.88	1733	1735	- 2	-0.1
	.195	2.44	2032	1910	+122	+6.0
	.262	3.25	2141	2110	+ 31	+1.4
FL-17C-12	.081	1.00	1453	1400	+ 53	+3.6
	.163	1.86	1821	1745	+ 76	+4.2
	.200	2.25	1830	1850	- 20	-1.1
	.252	2.86	2106	2060	+ 46	+2.2
	.312	3.72	2183	2250	- 67	-2.8
	.350	4.17	2367	2360	+ 7	+0.3
	.400	4.76	3008			
	.450	5.36	2445CP			
FL-17C-14	.081	.88	1290	1328	- 38	-2.9
	.160	1.72	1630	1660	- 30	-1.8
	.191	2.06	1740	1765	- 25	-1.4
	.240	2.63	1848	1879	- 26	-1.4
FL-17C-16	.080	.86	1373	1358	+ 15	+1.1
	.161	1.77	1856	1887	- 31	-1.8
	.190	2.04	1680	1770	- 90	-5.4
	.240	2.67	1900	1980	- 80	-4.2
	.312	3.30	2163	2169	- 6	-0.3
	.35	3.76	2330	2267	+ 63	+2.7

(Continued)

TABLE III (Continued)

45° Obliquity						
Flechette	e	e/d	V_{50}	V_L	ΔV	% Deviation $\left(\frac{\Delta V}{V_{50}}\right) \times 100$
FL-17D-8	.158	2.29	2505	2600	- 95	-3.8
	.188	2.84	2825	2935	-110	-3.8
	.250	3.47	3575	3492	+ 83	+2.3
	.313	4.33	3955	4030	- 75	-1.8
FL-17	.100	1.30	1822	1773	+ 49	+2.7
	.120	1.57	1913	1970	- 57	-2.8
	.188	2.17	2306	2290	+ 16	+0.7
	.188	2.61	2460	2546	- 85	-3.5
	.252	3.50	2934	3010	- 76	-2.6
	.316	4.38	3448	3385	+ 63	+1.8
FL-17C-13	.160	1.80	2340	2380	- 38	-0.9
	.189	2.25	2783	2643	+140	+5.3
	.250	2.98	3099	3170	- 71	-2.3
	.314	3.74	3346HP			
FL-17C-16	.159	1.71	2180	2215	- 35	-2.5
	.187	2.01	2395	2480	- 85	-3.7
	.250	2.69	2815	2970	-155	-5.5
	.312	3.38	3440	3425	+ 15	+0.4

SYMBOLS:

e = Target thickness (inches)
e/d = Ratio of target thickness to flechette diameter
V_{50} = Measured army ballistic limit (ft/sec)
V_L = Calculated ballistic limit (ft/sec)
ΔV = (V_{50} - V_L)
HP = Highest partial penetration

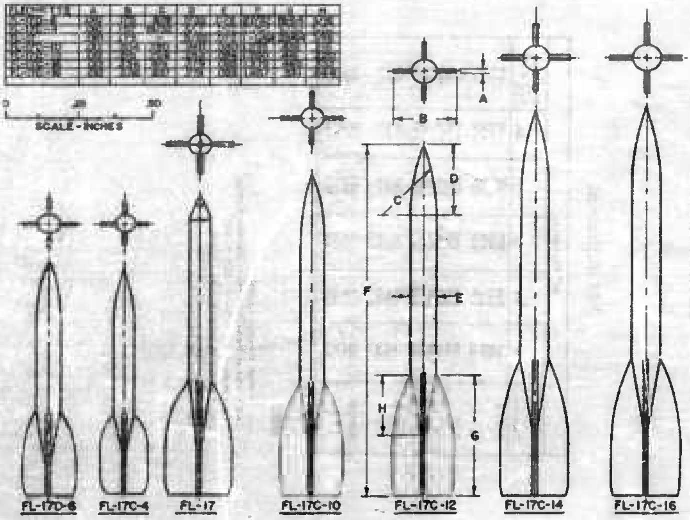
SCALE - INCHES
A
B
C
D
E
F
G
H
FL-17D-6
FL-17C-4
FL-17
FL-17C-10
FL-17C-12
FL-17C-14
FL-17C-16

FIGURE 1

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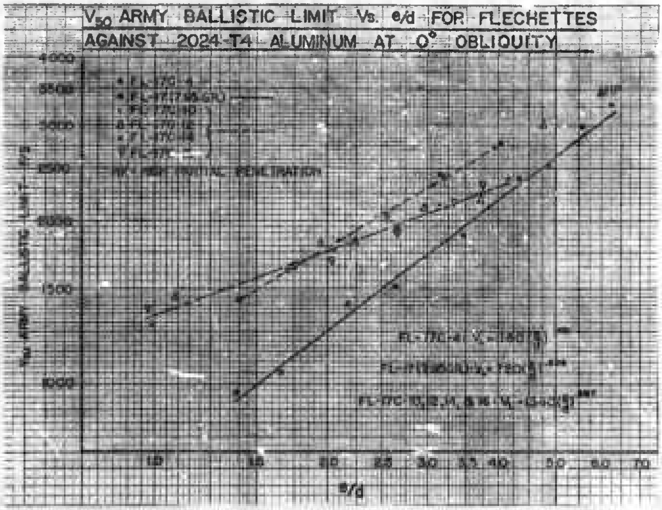

FIGURE 2

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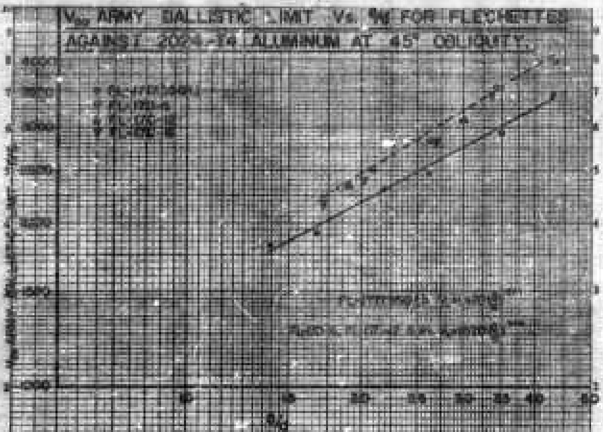

FIGURE 3

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